ADVANCED REACTOR, FUEL CYCLE, AND ENERGY PRODUCTS WORKSHOP FOR UNIVERSITIES

Advanced Fuel Development

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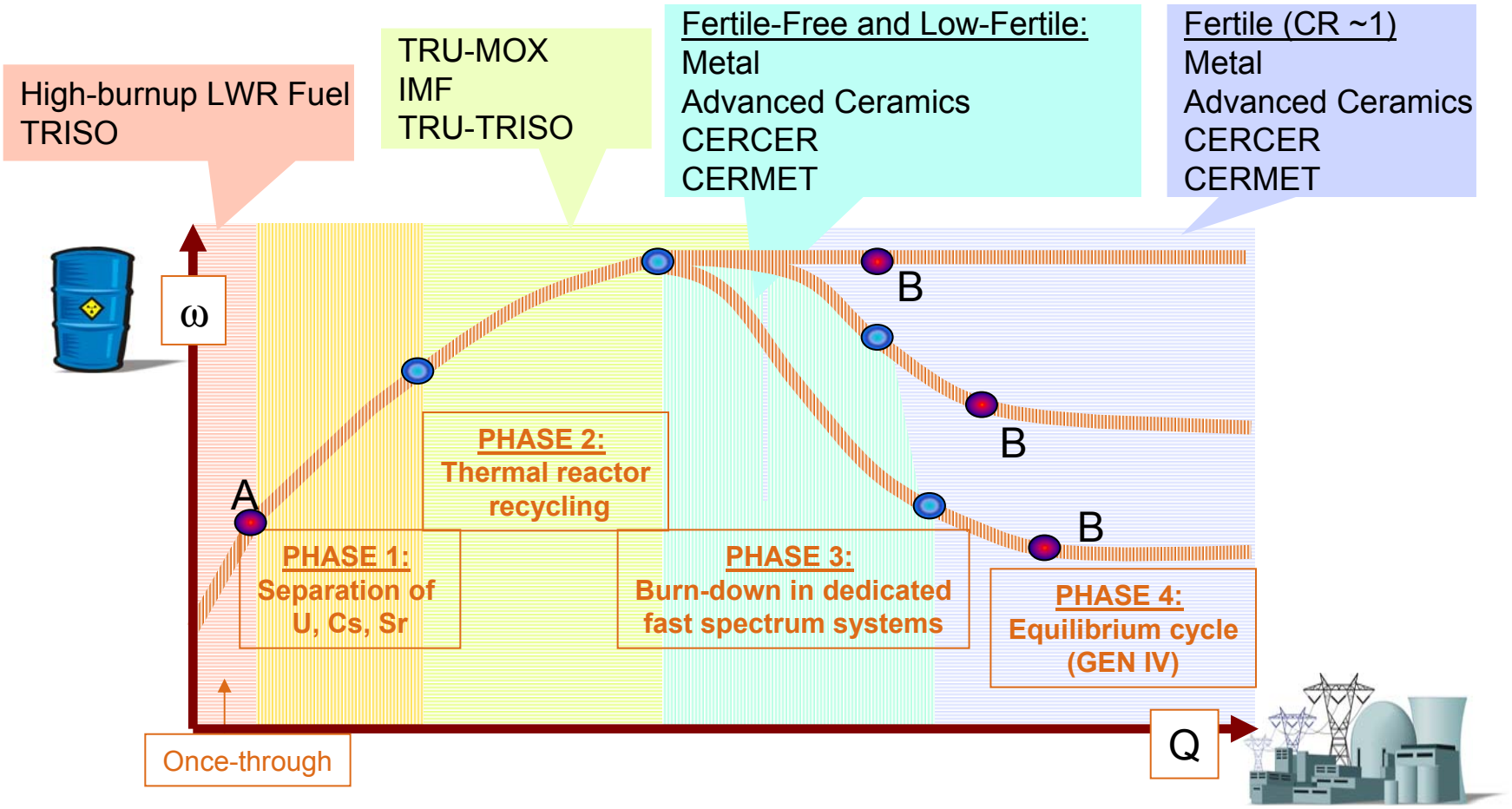
National Technical Director (kop@lanl.gov)

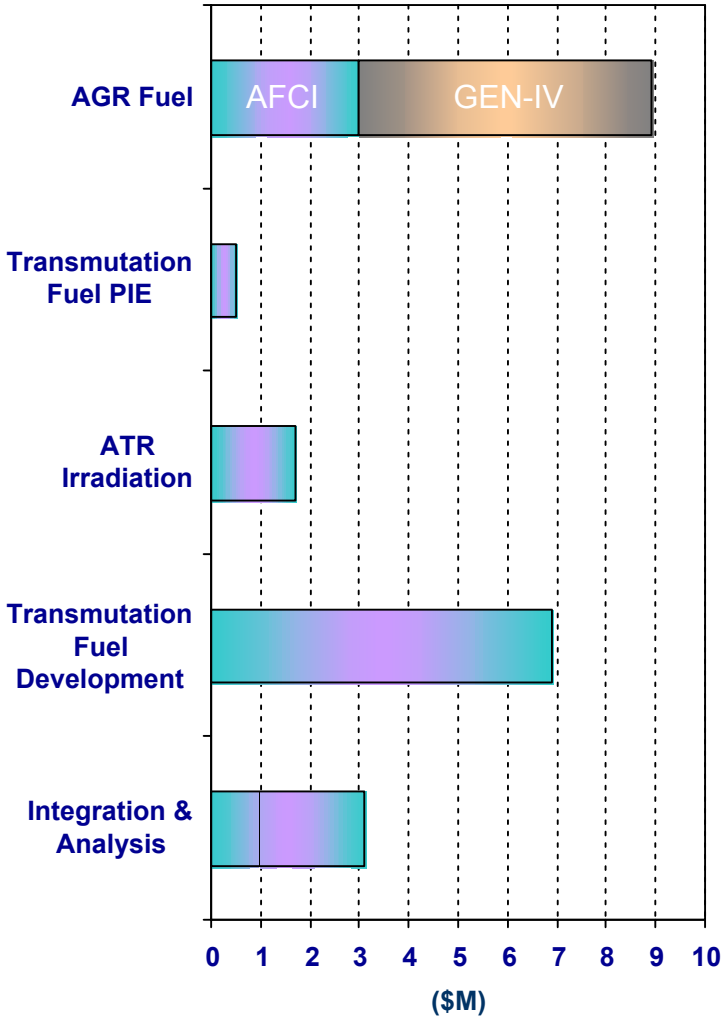
Workshop for Universities
Hilton Hotel, Gaithersburg, MD
March 4-5, 2004

The fuel development program covers fuels and cladding research for multiple phases of the fuel cycle evolution . The scope keeps growing…



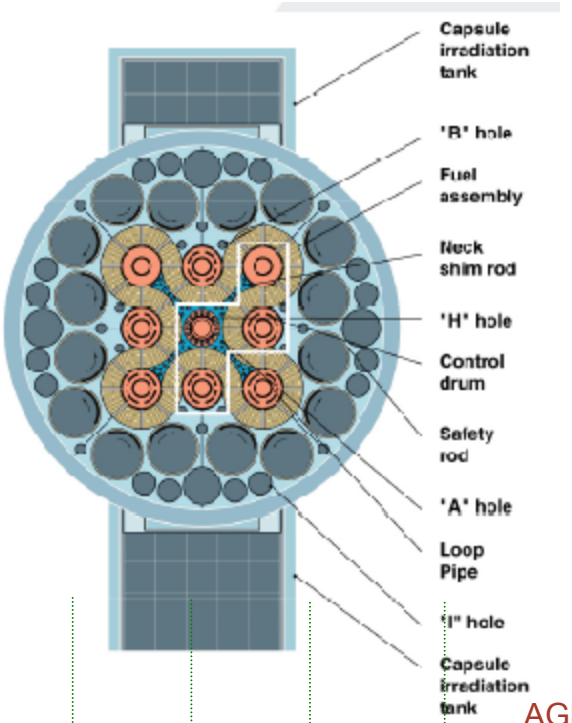
ω = F(volume, radiological risk, short-term heat load, long-term heat load,plutonium mine)

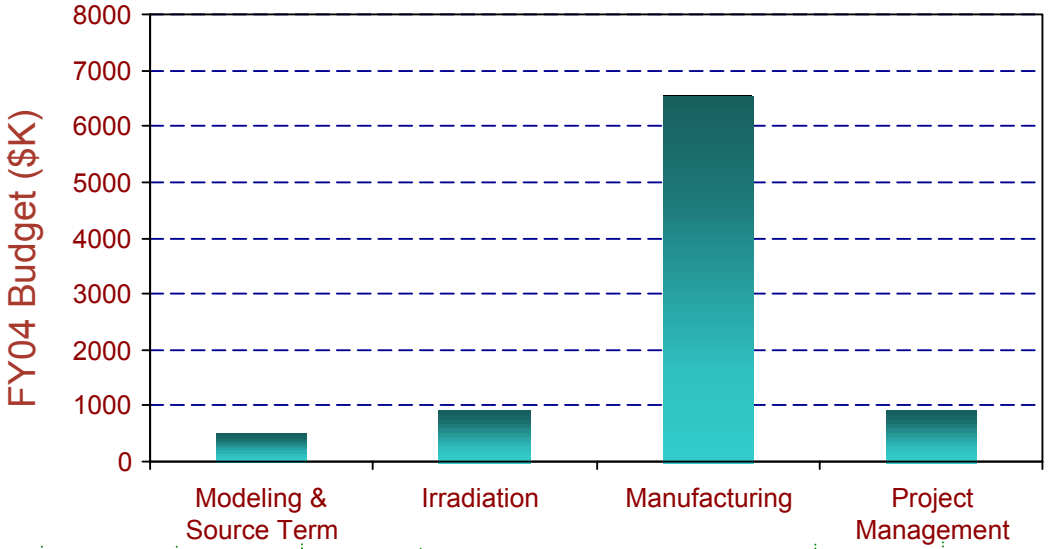
In FY04, the total budget of fuel development activities is $21 M.



- AGR Fuel
  - UCO TRISO fuel development with emphasis on fuel manufacturing for AGR-1 test in ATR
- Transmutation fuel PIE
  - GE-2000 cask interface design for transferring ATR samples to HFEF.
- ATR Irradiation
  - LWR-1 Tests (mixed oxide with Np)
  - AFC-1 Irradiations (low-fertile and non-fertile metal and nitride fuels)
  - GFR-1 Irradiation (dispersion fuel matrix materials for gas fast reactor)
- Transmutation Fuel Development
  - Process development, fabrication and characterization of
    - Mixed oxide fuels
    - Nitride fuels
    - Metal fuels
    - Dispersion fuels
- Integration and Analyses
  - Project management
  - Analyses (e.g. IMF implementation)
  - International collaborations (FUTURIX)
  - University support (R&D contracts, student and professor support)

The FY'04 emphasis of TRISO fuel development is the particle fuel fabrication for the shake-down test in ATR





AGR-8: Fission Product Transport

AGR-7: Performance model verification

AGR-6: Qualification

AGR-5: Qualification

AGR-4: Fission Product Transport

AGR-3: Fission Product Transport

AGR-2: Performance

AGR-1: Shakedown

FY'04 FY'05 FY'06 FY'07 FY'08 FY'09 FY'10 FY'11 FY'12 FY'13 FY'14 FY'15

AGR Fuels

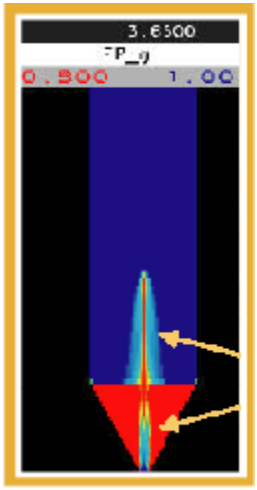
Coating Development
CVD Process Model Development

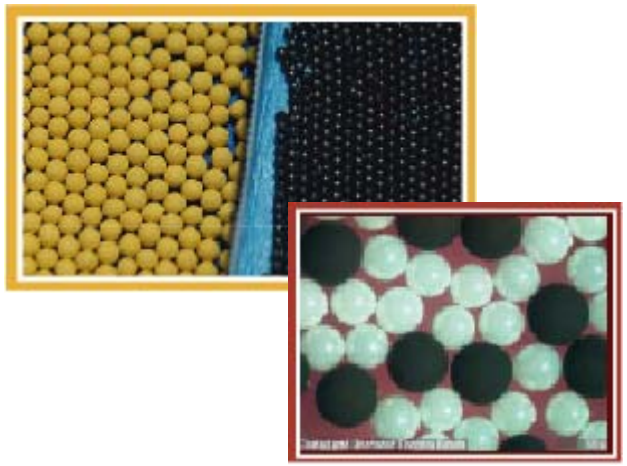
Institution: ORNL

PI: Dave Williams
e-mail: williamsdf2@ornl.gov

Scope and Objectives

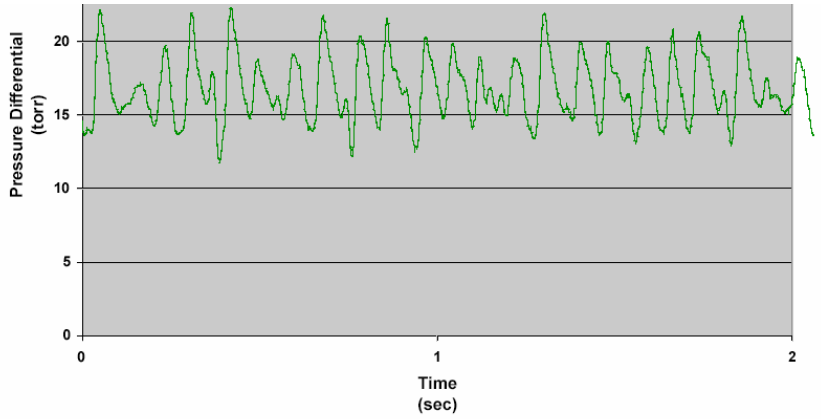
- Develop coating technology with the objective to meet the German standards.
- Test the coated particles in ATR to assess the irradiation performance.
- Transfer coating technology to BWXT for commercial scale fabrication.
- Develop and validate the MFIX code used for modeling the coating process (Chemical Vapor Deposition in a fluidized bed).





Accomplishments

- Considerable amount of coating testing is being done at ORNL using primarily surrogate materials using a small coater (2-in coater).
- MFIX code is being run and compared to data obtained using the small coaters. Experimental and analytical work is being carried out in collaboration with University of Tennessee.



AGR Fuels

Compacting Development
Basic and Advanced Characterization Development

Institution: ORNL

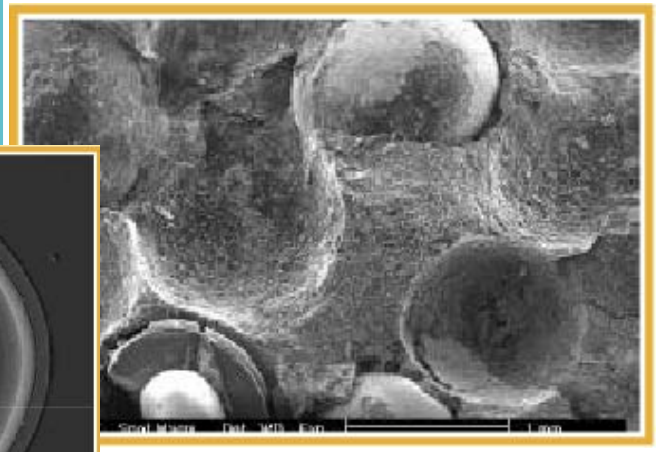
PI: Dave Williams
e-mail: williamsdf2@ornl.gov

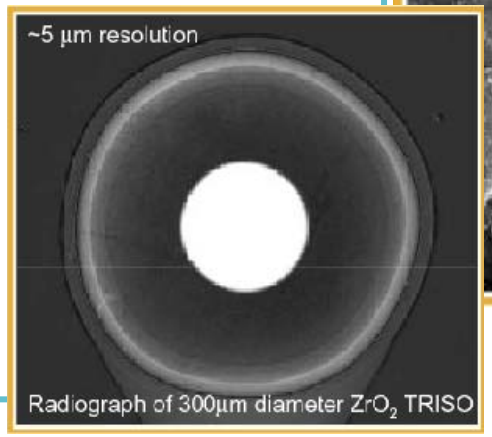
Scope

- Develop compacts for TRISO fuel that meet the German irradiation performance standards.
- Develop the over-coating technology that reduces the pressure on the particles during the compacting process.
- Characterize the archived German particles
- Develop advanced characterization techniques
- Transfer compacting and characterization technologies for industrial use.

Accomplishments

- Overcoating technology is being developed to minimize the potential particle damage during compacting.
- Characterization of German particles is ongoing.
- Advanced characterization technologies:
  - Non-destructive testing
  - Automated characterization

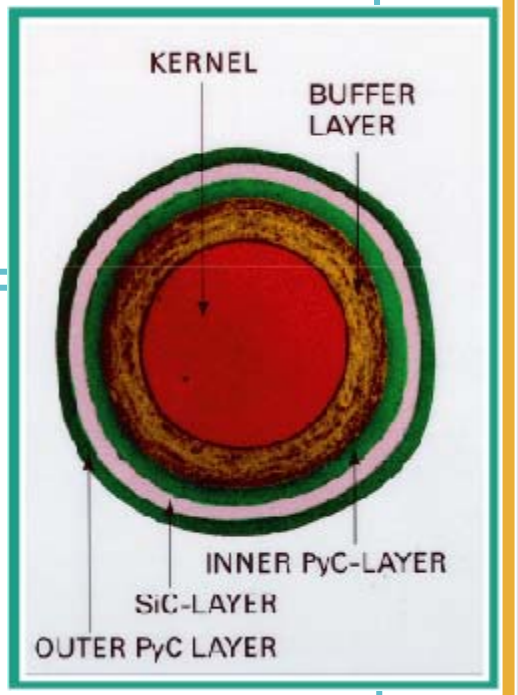


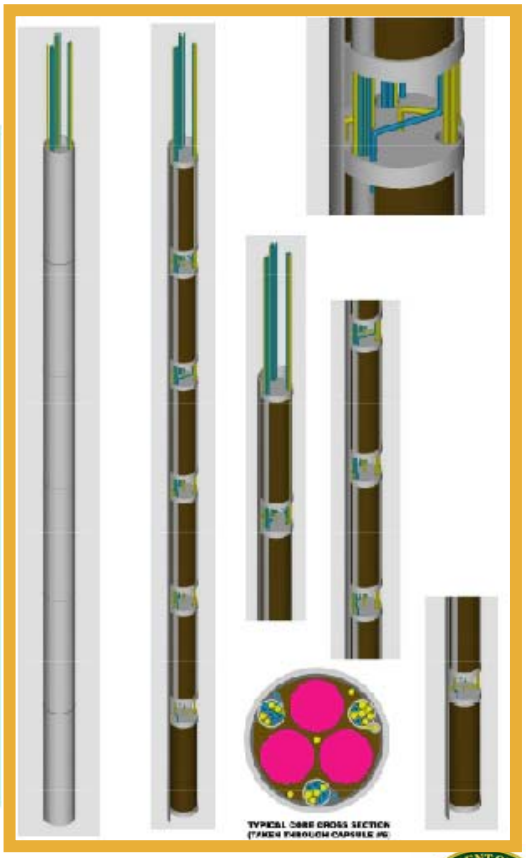


Scope

- Fabrication, testing and qualification of UCO fuel particles for use in VHTR.
- Series of tests in AGR under NQA-1 in ATR 2005 - 2012 leading to fuel qualification.

PI: Dave Petti
e-mail: pti@inel.gov





Accomplishments

- Fabricated LEO2, NUOC kernels
- Kernels are being shipped to ORNL for coating and compacting.
- Conceptual design of AGR-1 is completed.

AGR Fuels

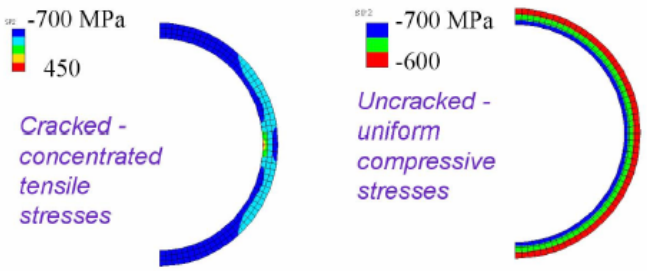
Fuel Performance Modeling
Fission Product Transport and Source Term

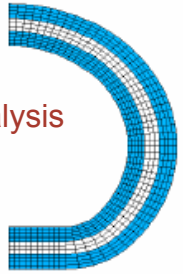
Institution: INEEL

PI: Dave Petti
e-mail: pti@inel.gov

Scope

1. Properties of fuel coating layers under normal operation (NERI) & properties of fuel coating layers under accident conditions (French I-NERI)
2. Code Benchmarking
   - In FY 2004, the actual PARFUME calculations for the eight benchmarking cases will be performed.
3. Develop improved accident code
   - PARFUME code modifications to address accident conditions and performance of calculations under both heating test conditions and conduction cool down conditions.
4. Document status of benchmark calculations and code improvement work (Sept. 30, 04)

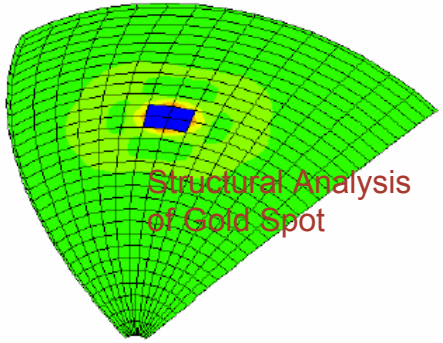




Structural Analysis of Asphericity

Accomplishments

- PARFUME is being used to anlayze a number of various scenarios for TRISO particles
  - Cracked coating
  - Delamination and gold spot
- TMAP model (1D diffusion through the particle fuel) is being developed and benchmarked to be used use for fission product transport and source term calculations

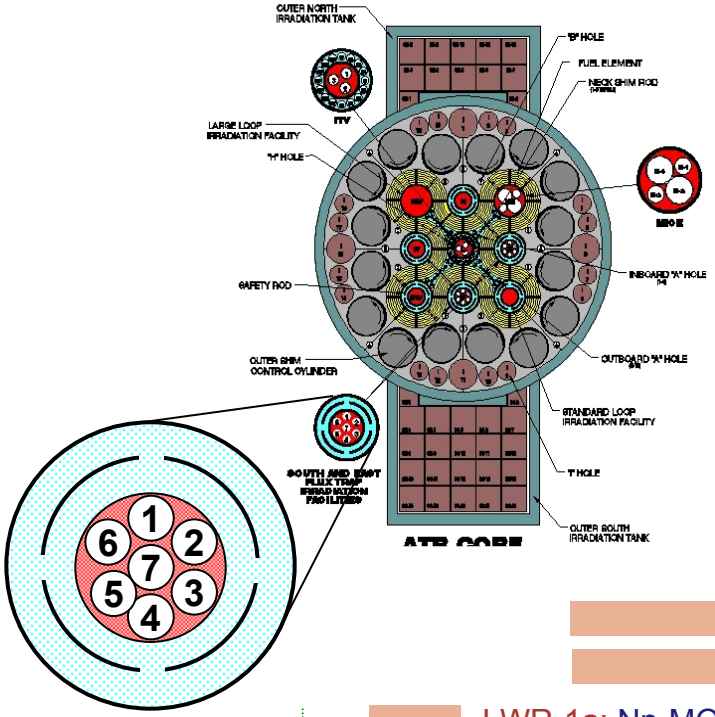


Structural Analysis of Gold Spot

Some specific University research areas of interest for the TRISO fuel development are

- Evaluation and Development of Thermocouples for High Temperature Nuclear Environments in the Advanced Test Reactor, Idaho National Lab.
- Optimization of the gamma-ray detector types for Advanced Test Reactor (ATR) fission product monitoring system
- Methods to evaluate and limit fission product plating in ATR fission product monitoring system tubing
- Thermochemical Analysis of Multi-Composition Kernels for Coated Particle Fuel
- High Temperature Gettering of Cesium, Silver, Iodine, and Tellurium in Advanced Gas Cooled Reactors
- Evaluation of natural graphite properties after adsorption of fission products
- Compacting development evaluation and innovative methods
- Detailed reaction kinetics for CVD process and incorporation into MFIX
- Experimental and numerical investigation of 6-inch coater hydrodynamics

ATR irradiation and PIE for transmutation involve mixed-oxide, IMF, americium targets, nitride , metal and dispersion fuels.



FUTURIX-MI (Phenix)

FUTURIX-FTA (Phenix)

LWR-2a: TRU-MOX, IMF, Am target (medium burnup)

LWR-2a: TRU-MOX, IMF, Am target (medium burnup)

LWR-1c: TRU-MOX, WG-MOX, RG-MOX (high-burnup)

LWR-1b: TRU-MOX, WG-MOX, RG-MOX (medium-burnup)

LWR-1a: Np-MOX, WG-MOX, RG-MOX (low-burnup)

GFR-1: Dispersion fuel with U (high-burnup)

GFR-2a: Dispersion fuel with U (medium-burnup)

AFC-1G: Low-fertile and non-fertile nitride (high-burnup)

AFC-1H: Low-fertile and non-fertile metal (high-burnup)

GFR-1: Dispersion fuel matrix irradiation (low-burnup)

AFC-1F: Low-fertile metal (low-burnup)

AFC-1AE: Non-fertile and low-fertile nitride (low-burnup)

AFC-1D: Non-fertile metal (low-burnup)

AFC-1B: Non-fertile metal (medium burnup)

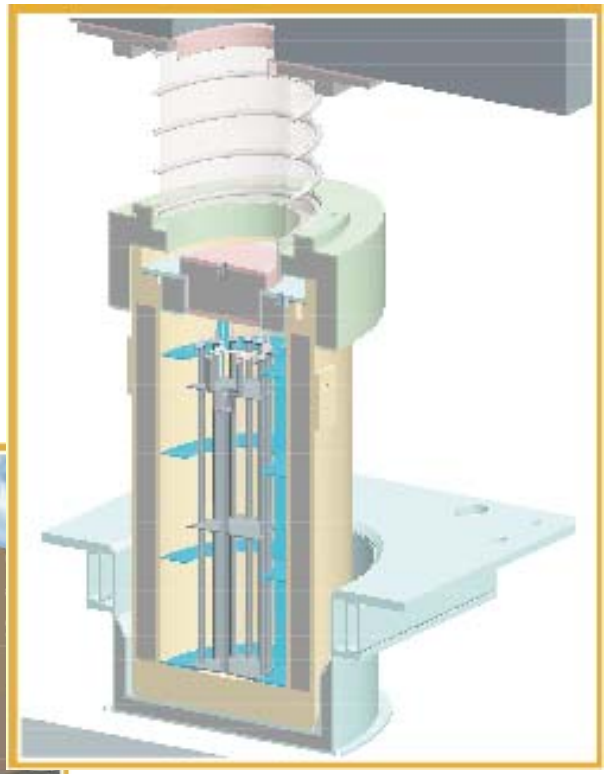
FY'03 FY'04 FY'05 FY'06 FY'07 FY'08 FY'09

Transmutation Fuel PIE	GE-2000 Cask Interface Preparations for PIE	Institution: ANL

Scope

- Preparation of the GE-2000 interface at HFEF
- Subsequent PIE of samples from the following tests
  - AFC-1
  - LWR-1 & 2,
  - GFR-1, 2 &3
- PIE on cadmium baskets
- FUTURIX FTA and MI PIE will be performed at HFEF (ANL) and CMR (LANL) hot cells

PI: Bruce Hilton
e-mail: bruce.hilton@anl.gov



Accomplishments

The HFEF will be ready to start the PIE on the samples from irradiations experiments by late summer'04

Transmutation Fuel Irradiation	ATR Irradiations: Engineering, Experiment Handling & Analyses	Institution: INEEL

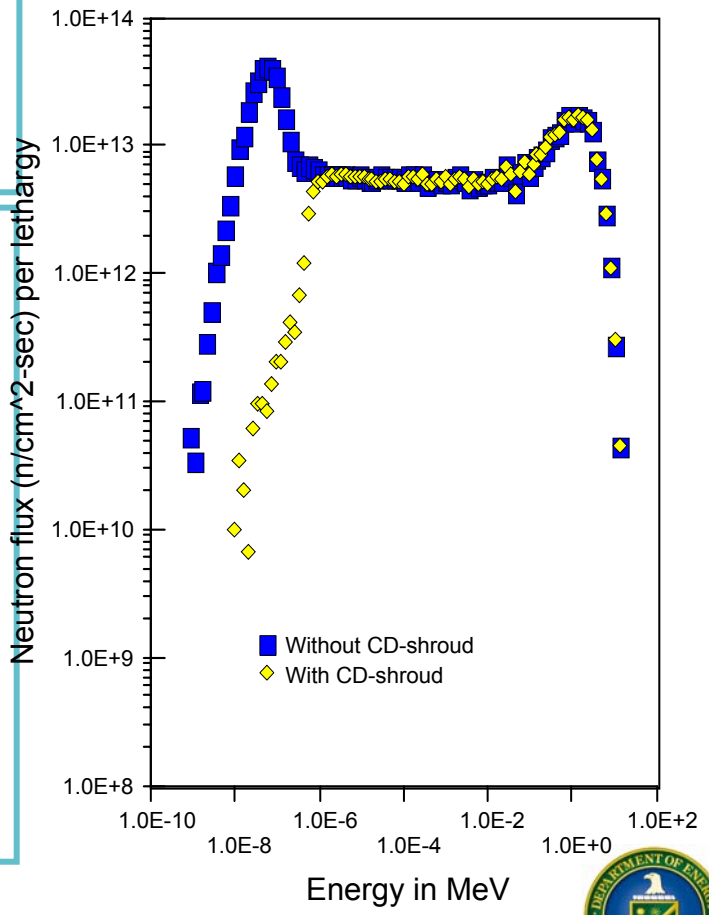
Scope

- Design, analyze and conduct irradiation tests for fast and thermal spectrum transmutation fuels in ATR.
- Prepare and get approval on necessary safety documentation

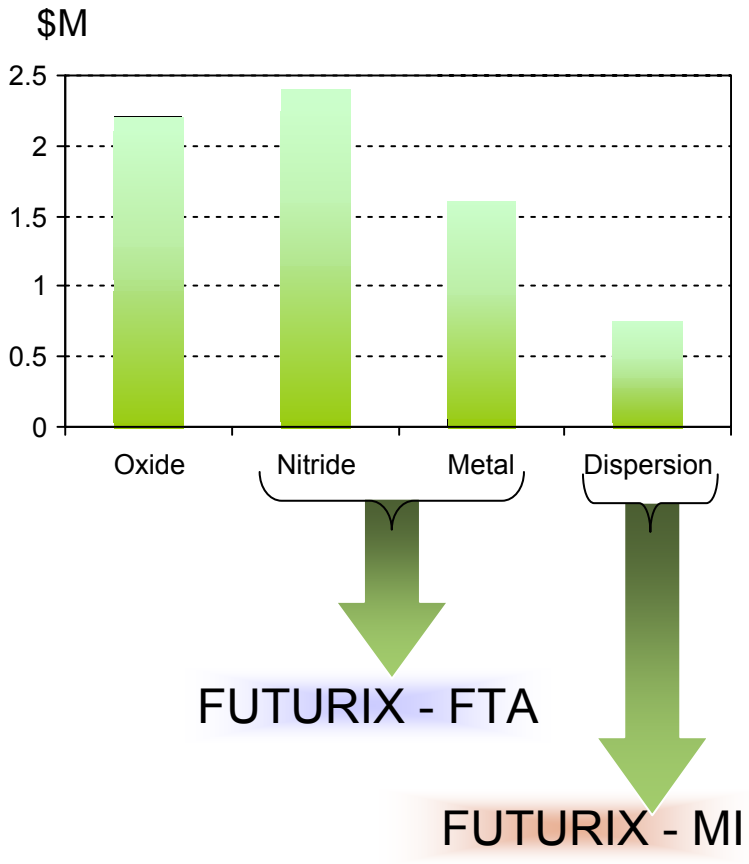
PI: Richard Ambrosek
e-mail: rga@inel.gov

Accomplishments

- AFC-1, LWR-1, GFR-1 tests are ongoing
  - AFC-1: Non-fertile, and low-fertile metal and nitride fuels containing U, Pu, Np, Am (low and & intermediate burnup)
  - LWR-1: Np-MOX fuel, low burnup
  - GFR-1: Matrix materials for GFR-1
- Preparing for the next series after core-change-out
  - AFC-1 G &H: high burnup metal and nitride fuels
  - AFC-1B: high burnup for TRU-MOX
  - LWR-2: TRU-MOX, TRU-IMF, Am targets



Transmutation Fuel Development is a major focus of the AFCI program



- Oxide Fuels
  - TRU containing mixed oxide fuel process development fabrication and characterization
  - Modeling
- Nitride Fuels
  - TRU containing fertile-free or low-fertile nitride fuel process development fabrication and characterization
  - Modeling
- Metal Fuels
  - TRU containing fertile-free or low-fertile metal fuel process development fabrication and characterization
  - Modeling
- Dispersion Fuels
  - GFR fuel matrix materials development
  - Aluminide matrix assessment

Transmutation Fuel: Oxide

Oxide Fuels Process Development, Analyses, Fabrication and Characterization

Institution: LANL

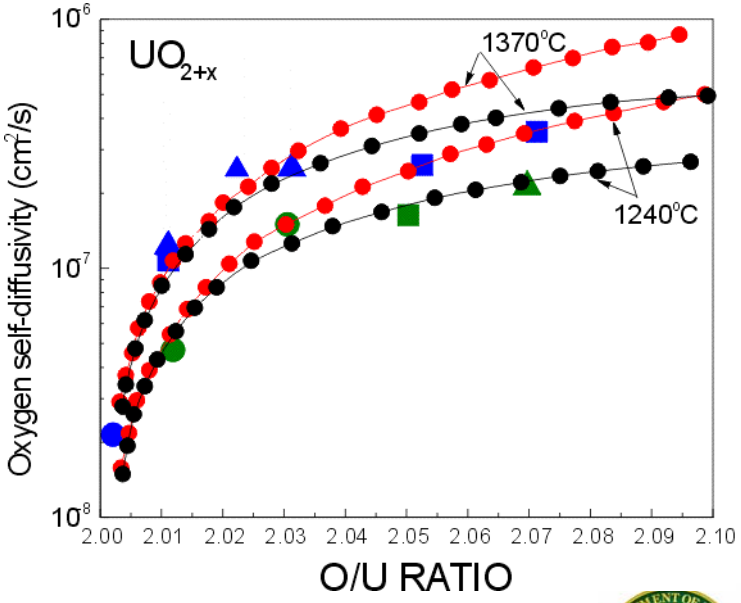
PI: Stuart Maloy
e-mail: maloy@lanl.gov

Scope

- Fabrication process development and characterization of TRU bearing oxide fuels for fast spectrum transmutation
  - Low-fertile and non-fertile
- Modeling of fabrication processes and irradiation performance of TRU-bearing metal fuels

Accomplishments

- Initial set of Np-Pu-U mixed oxide fuels were fabricated and characterized.
- They are being irradiated in ATR for a side-by-side comparison with weapons-grade and reactor-grade MOX fuels.
- Process optimization tests are ongoing
- High-burnup fuels are being fabricated
  - Including the investigation of incorporating Am into the fuel.
- Oxygen diffusion model development and analyses started.
- Synthesis model to support the feed preparation started.
- Heat transfer (TRUCHAS) model for the fuel pins started



Transmutation Fuel: Nitride	Nitride Fuels Process Development, Analyses, Fabrication and Characterization	Institution: LANL

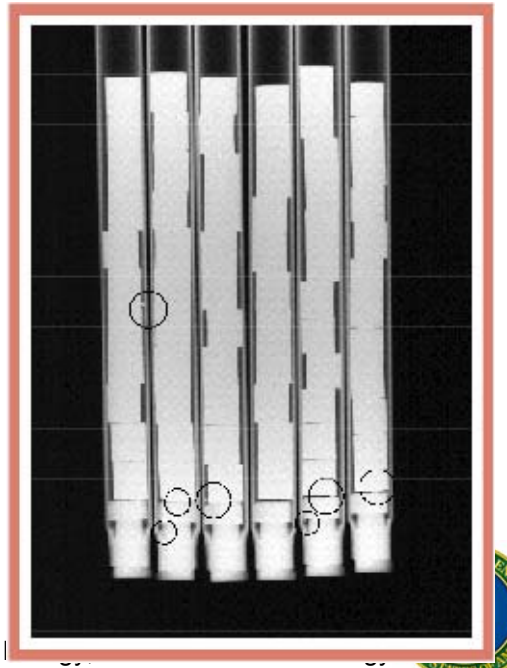
PI: Stuart Maloy
e-mail: maloy@lanl.gov

Scope

- Fabrication process development and characterization of TRU bearing nitride fuels for fast spectrum transmutation
  - Low-fertile and non-fertile
- Modeling of fabrication processes and irradiation performance of TRU-bearing nitride fuels

Accomplishments

- A series fertile-free and low-fertile (Pu-Np-Am-Zr) nitride pellets have been fabricated and characterized
- They are being irradiated at ATR to low-burnup
- Fabrication of high-burnup fuel pellets continue
- Process optimization tests are ongoing
- Surrogate (ZrN) and real nitride pellets are being fabricated for thermal diffusivity measurements and sodium bonding tests to be conducted at ANL.
- Nitride phase diagram modeling activities continue.
- The ion-beam irradiated samples of ZrN are being analyzed for helium-release and radiation damage.
- Collaboration with ASU continues to assess microstructural evolution and mechanical properties of nitrides



Transmutation Fuel: Metal	Metal Fuels Process Development, Analyses, Fabrication and Characterization	Institution: ANL

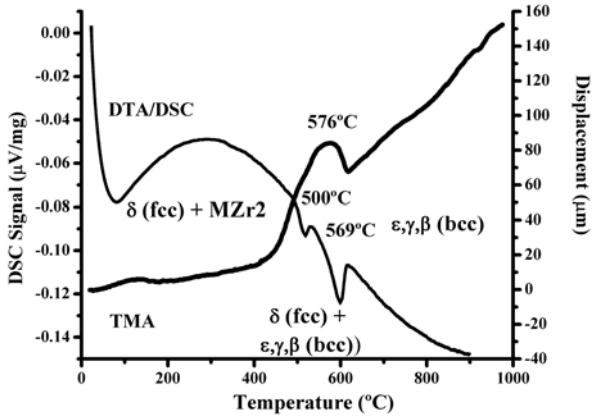
Scope

- Fabrication process development and characterization of TRU bearing metal fuels for fast spectrum transmutation
  - Low-fertile and non-fertile
- Modeling of fabrication processes and irradiation performance of TRU-bearing metal fuels

PI: Steve Hayes
e-mail: steven.hayes@anl.gov

Accomplishments

- A series of low-fertile and non-fertile metal fuels have been fabricated, characterized and are being irradiated in ATR
- Microstructure/phase equilibria, thermal analyses and thermal conductivity of AFC-1 and FUTURIX fuels continue, with early emphasis on thermal analyses.
- Improved sodium bonding process development tests are starting soon.



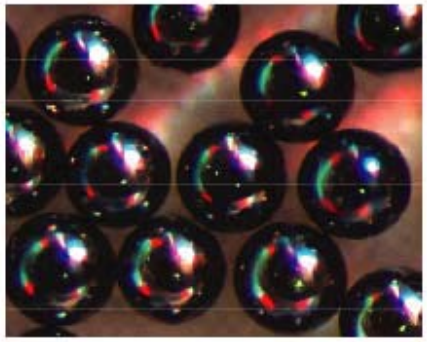
Before After

Transmutation Fuel: Dispersion	Dispersion Fuel Development	Institution: ANL

Scope

- Define dispersion fuel concepts for fast reactor applications
  - Emphasis on GFR
- Develop and test matrix materials
- Fabrication process development and characterization of TRU bearing dispersion fuels for fast reactors and fast spectrum transmutation
  - Low-fertile and non-fertile
- Modeling of fabrication processes and irradiation performance of TRU-bearing dispersion fuels

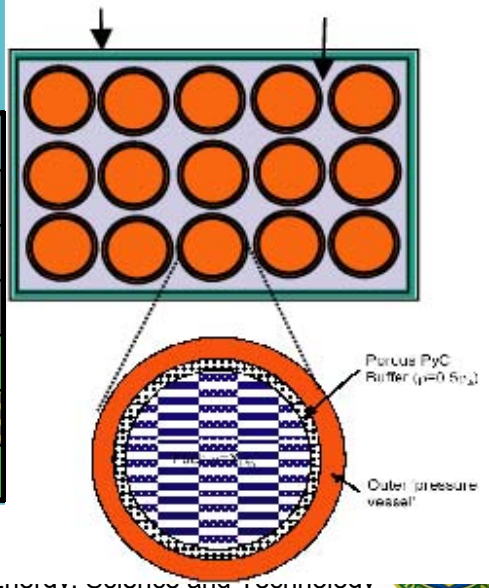
PI: Mitch Meyer
e-mail: mitchell.meyer@anl.gov



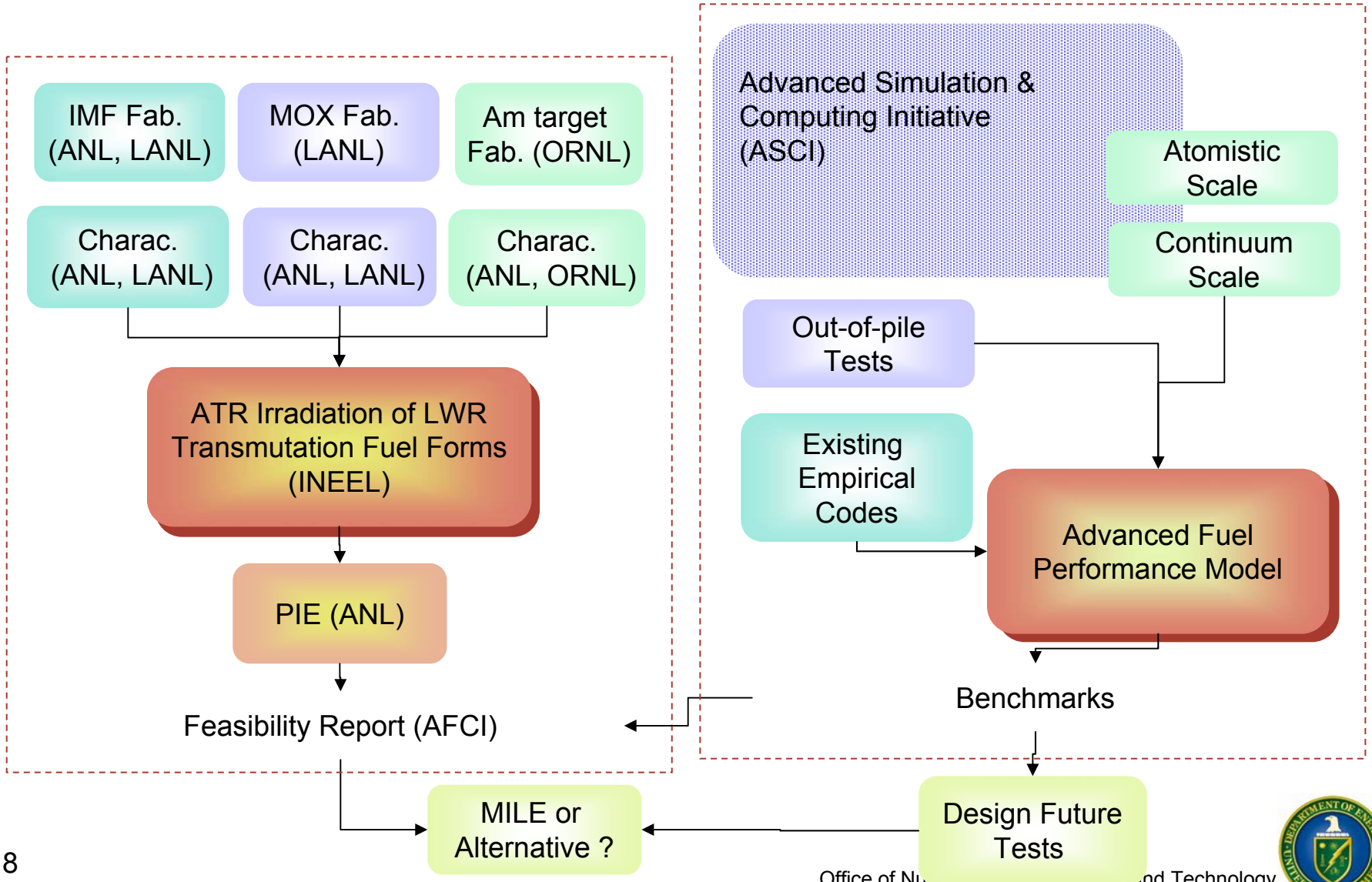
Accomplishments

- Initial screening of potential matrix materials completed
- A materials irradiation test in ATR prepared and irradiation started
- Negotiations continue for FUTURIX-MI collaboration with CEA.
- Modeling efforts started
- Particle fabrication methods are being assessed

Oxides	Carbides	Nitrides
Al_2O_3	**SiC**	AlN
CeO_2	**TiC**	CeN
$MgAl_2O_4$	VC	Si_3N_4
MgO	YC_2	**TiN**
Y_2O_3	**ZrC**	YN
ZrO_2		**ZrN**



Two major US-lead initiatives are being planned to focus relevant National and International research



Models and Simulations, Short-Term

PI: Marius Stan
e-mail: mastan@lanl.gov

Phase diagrams show conflicting info (ex. UN stoichiometry)

U-N and Pu-N phase diagrams via thermo-chemistry

Optimization of the carbo-thermal reduction process is needed

Thermochemical model of oxide feed preparation

Mechanism and kinetics of species diffusion in ceramics unclear

Model of oxygen diffusion of in PuO_{2-x} and $UO_{2\pm x}$

Thermo-mechanical properties in fuel codes

Simulation of heat transfer in oxide fuels using FRAPCON and TRUCHAS

Models of mechanical properties must be predictive

Constitutive model of ZrN

Models and Simulations, Long-Term

PI: Marius Stan
e-mail: mastan@lanl.gov

Important phase diagrams are not known

- Am-N phase diagram via atomistic modeling
- Np-N phase diagram via atomistic modeling

Thermo-mechanical properties of new nitride compounds needed

- Electronic Structure calculations of temperature effects in nitrides

Multi-component phase diagrams needed (U-Np-Pu-Zr)

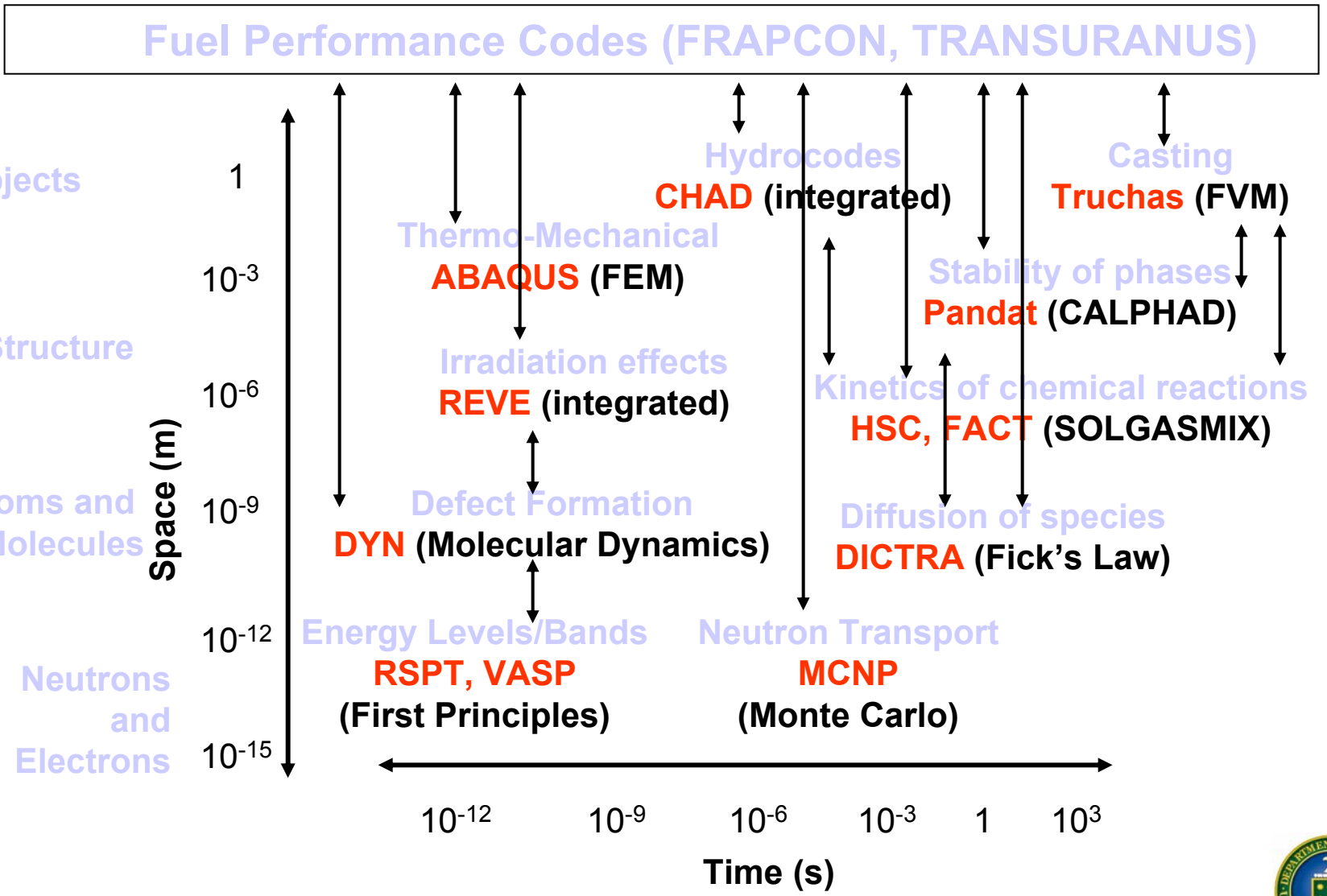
- Assessment of the Pu-Zr phase diagram
- Assessment of the Np-Zr phase diagram
- Assessment of the Pu-Np-Zr phase diagram

Defects formation and species mobility unclear

- Add charge transfer to atomic potentials and do accelerated molecular dynamics simulations

Scales/Codes/Methods

PI: Marius Stan
e-mail: mastan@lanl.gov



Workshops on Materials Modeling and Simulations For Nuclear Fuels

organized by the AFCI/LANL Modeling Team

MMSNF-1, June 9-10, 2003, Santa Fe, NM

www.lanl.gov/orgs/mst/nuclearfuels/

MMSNF-2, November 20-21, 2004, New Orleans, LA

www.lanl.gov/orgs/mst/mmsnf/

New ! MMSNF-3, June 17-18, 2004, Pittsburgh, PA

Following the ANS Summer Meeting

For information, contact Marius Stan at mastan@lanl.gov

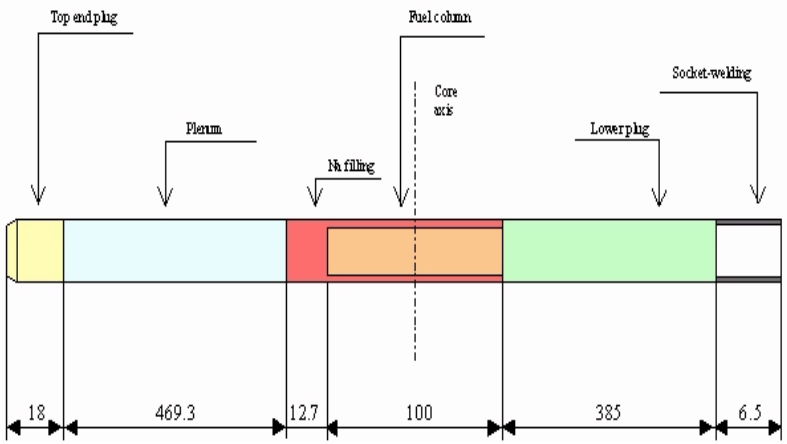
International Collaboration	FUTURIX-FTA	Institution: ANL/LANL

Non-Fertile Fuels	Bond	Fabricator
(48)Pu-12Am-40Zr	Na	ANL
$(Pu_{0.50}, Am_{0.50})N$ + 36-wt%ZrN	Na	LANL
$(Pu_{0.20}, Am_{0.80})O_2$ + 65-vol%MgO	He	CEA
$(Pu_{0.50}, Am_{0.50})O_2$ + 70-vol%MgO	He	CEA
$(Pu_{0.23}, Am_{0.25}, Zr_{0.52})O_2$ + 60-vol%Mo^{92} He	ITU	
$(Pu_{0.50}, Am_{0.50})O_2$ + 60-vol% Mo^{92}	He	ITU
Low-Fertile Fuels		
(35)U-29Pu-4Am-2Np-30Zr	Na	ANL
$(U_{0.50}, Pu_{0.25}, Am_{0.15}, Np_{0.10})N$	Na	LANL

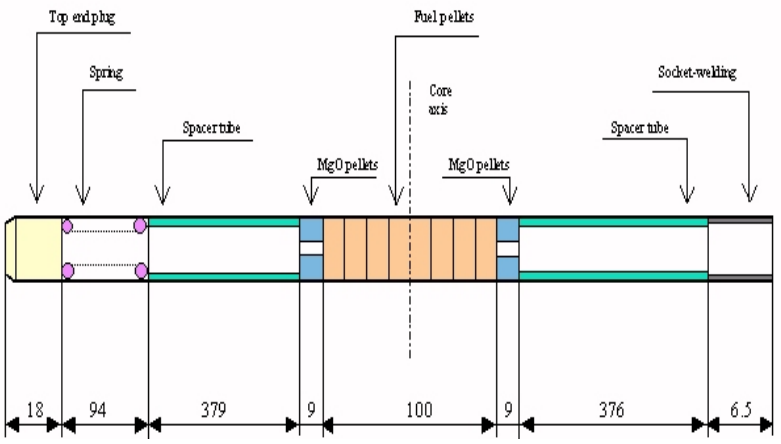
PI: Steve Hayes
e-mail: steven.hayes@anl.gov

19-pin experimental subassembly to be used
- 8 experimental pins
- 11 standard Phénix driver pins or dummies

Irradiation in Phénix ring 3 or 4
- Satisfies LHGR limit of 350 W/cm



Na-bonded fuels



He-bonded fuels

International Collaboration	FUTURIX-MI	Institution: ANL/LANL

EFFECT OF IRRADIATION ON PHYSICAL AND CHEMICAL PROPERTIES

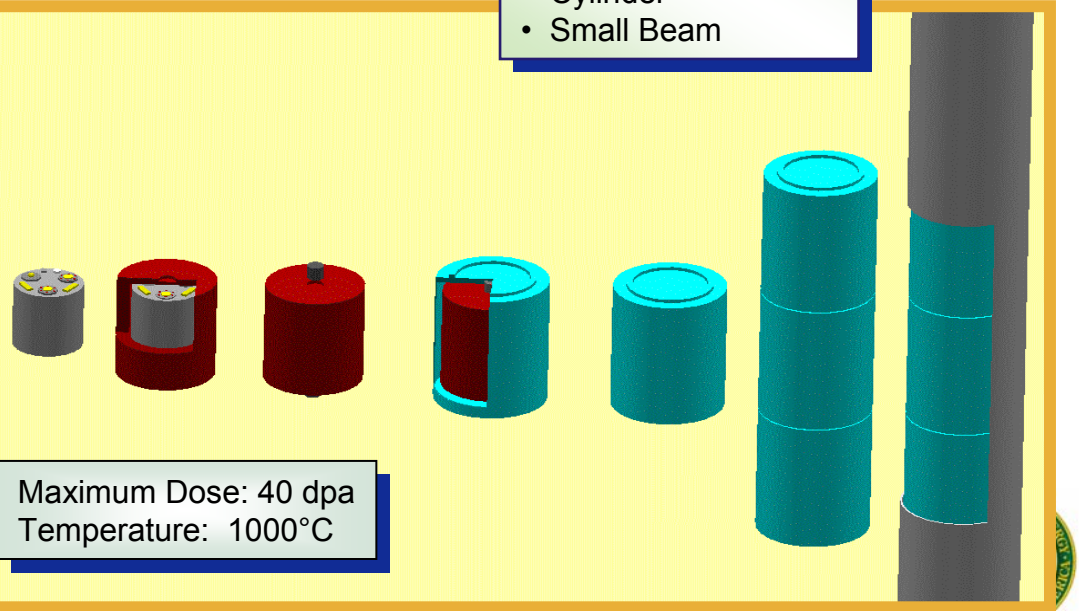
- DENSITY (SWELLING)
- MICROSTRUCTURE
- COMPOSITION - CRYSTALLOGRAPHIC PHASES
- ACTIVATION
- THERMAL PROPERTIES : Thermal Conductivity,Thermal Diffusivity, Heat Capacity, Linear Expansion
- MECHANICAL PROPERTIES : Young Modulus, Poisson ration, Hardness, Strength
- ELECTRICAL RESISTIVITY

PI: Mitch Meyer
e-mail: mitchell.meyer@anl.gov

INERT MATERIALS
α-SiC : 2 types (mono and polycrystal)
β-SiC: 2 types (mono and polycrystal)
ZrC : 2 types (micro and sub-micro.)
TiC
TiN
ZrN
Mo (Alloy)
SiC_f/SiC : 2D SiC_f/SiC : 3D
2 materials to be defined : TiN,SiC (other composition) NbZrC ?

SAMPLES

- Small Disk
- TEM Specimen
- Cylinder
- Small Beam



Maximum Dose: 40 dpa
Temperature: 1000°C

Some specific University research areas of interest for the transmutation fuel development are

- Fabrication process development for TRU bearing fuels
  - Process optimization & correlation of process parametres with irradiation performance parameters
  - Process modeling
  - Low temperature or low heat fabrication techniques for Am bearing fuels
- Fuel characterization techniques
- Design of separate effect irradiation experiments
  - Analyses of the irradiation experiments and resulting data
- Development of advanced PIE methods
- Development and assessment of advanced cladding concepts
- Development and assessment of advanced matrix materials for dispersion fuels/inert matrix fuels for LWRs and fast reactors
- Fuel concepts for advanced LWRs/High-burnup fuels
- Fuel concepts for GFR, design analyses and testing
- Design and assessment of remote fuel fabrication facility
- Advanced fuel modeling (atomistic scale to continuum scale to performance codes)

Multi-institutional fuel development working group (FDWG) is well established and is essential in the successful conduct of the research activities

Name	Institution	Primary Expertise
Todd Allen	UW	Clad materials
Richard Ambrosek	INEEL	Fuel irradiation
Doug Crawford	ANL	LFR system integration manager
Jess Gehin	ORNL	Mixed oxide fuels
Steve Hayes	ANL	Metal, dispersion and inert matrix fuels
Steve Long	LANL	Ceramic fuels
Stuart Maloy	LANL	Clad materials
Ken McClellan	LANL	Ceramic fuel characterization and modeling
Mitch Meyer	ANL	Metal, dispersion and inert matrix fuels
Kemal Pasamehmetoglu	LANL	National Technical Director, Chairman of FDWG
Eric Shaber	INEEL	Fabrication processes and TRISO fuel
Steve Sheetz	WSRC	Fuel deployment and facility design
Finis Southworth	INEEL	NGNP system integration manager
Mike Todosow	BNL	Fuel safety envelope
Jim Tulenko	UF	Fuel fabrication, modeling and IMF
Debbie Utterbeck	INEEL	Fuel irradiation
Kevan Weaver	INEEL	GFR system integration manager
Dave Williams	ORNL	TRISO fuel
Steve Willson	LANL	Ceramic fuels

University research PIs will be invited to selected FDWG meetings:

- *to participate in the discussion; and*
- *to present to status of their research*